MEASUREMENTS WITH THE NANOVNA

Part 4: Measuring the characteristics of unknown toroids and identifying them

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Preface

In my shack is an IKEA container marked as "Ring cores". This one is full of cores and ferrite rods of all shapes and sizes that I am reviewing. They are the result of 44 years of amateur radio, gathered for all kinds of purposes. You immediately recognize some of those types. Those are the purple, the 4C6, or nowadays 4C65 types. Those were the ones you bought from the HamRadio Service Bureau to combat low-frequency interference to your neighbours. I can tell you that I now use completely different ferrites for this, but back then you could not familiarize yourself with that as much as today and the choice was not yet huge either. There are toroids of different colours in the tray and you can sometimes find out which type you are dealing with. Noticeable is that black and beige occur very regularly, without any inscription, and for some cores, the color is difficult to see (bluish purple or purplish-blue, cream, or white).

In this article, I want to use the nanoVNA to identify the cores, and that is certainly possible.

Without immediately reaching for the measuring instruments, we see that ring cores have several external "properties". when you inspect them:
1. Size (outside diameter, height, hole diameter)
2. Colour coding or a layer of lacquer around it (few tenths of a mm thick)

Measurements

Requirements:

The intention is to measure as practically as possible without setting up a complete measuring lab. For this article of course we will use the nanoVNA and a caliper. I also use the mini Ring Core Calculator (a free downloadable program). It is a nice piece of software with lots of data for different cores that are neatly sorted, and it contains some handy calculation tools that you can use well.

There is Measure and Re-measure:

Without a doubt, the easiest measurements are "post measurements". If you know what kind of core you have and you measure it, you are satisfied when you are close with your results. It is totally different if you do NOT know what kind of core you have in front of you and you have yet to find out. This requires a somewhat more extensive approach because some cores have properties that at first look very similar.

Challenges:

Manufacturers publish specifications based on measurements with only one winding. This is related to it avoiding the capacitance between multiple windings and keeping the winding wire as short as possible. The length of the wire alone causes a phase shift, after all a piece of wire is a certain amount of wavelengths long. So measure with a short winding wire and at the lowest possible frequency. Without that precaution the impedance measurement you might get unreliable answers.

A second challenge has to do with a picture of specs from the Ferroxcube manual (see reference). There are many different cores. The example below shows the data of 4C65 material. Formerly with a purple colour, nowadays they are often coated white (with a small purple dot on it if you are lucky).

Ferroxcube

Material specification 4C65

4C65 SPECIFICATIONS

Low permeability NiZn ferrite for use in RF tuning, wideband and balun transformers.

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤10 kHz; 0.25 mT	125 ±20%	
B	25 °C; 10 kHz; 3000 A/m	≈ 380	mT
	100 °C; 10 kHz; 3000 A/m	≈ 340	
$\tan\delta/\mu_i$	25 °C; 3 MHz; 0.25 mT	$\leq 80 \times 10^{-6}$	
	25 °C; 10 MHz; 0.25 mT	$\leq 130 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 350	°C
density		≈ 4500	kg/m^3

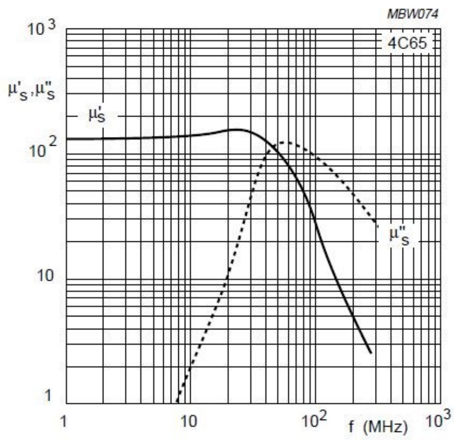


Fig.1 Complex permeability as a function of frequency.

We can extract three important measurement points from this to identify a core:

1. The μ_i, or the initial μ.
The μ_i is the relative permeability of the material, which is measured at a low frequency <10kHz (you are then dealing with virtually pure inductance and hardly any losses). For 4C65 it is 125 (+/- 20%).

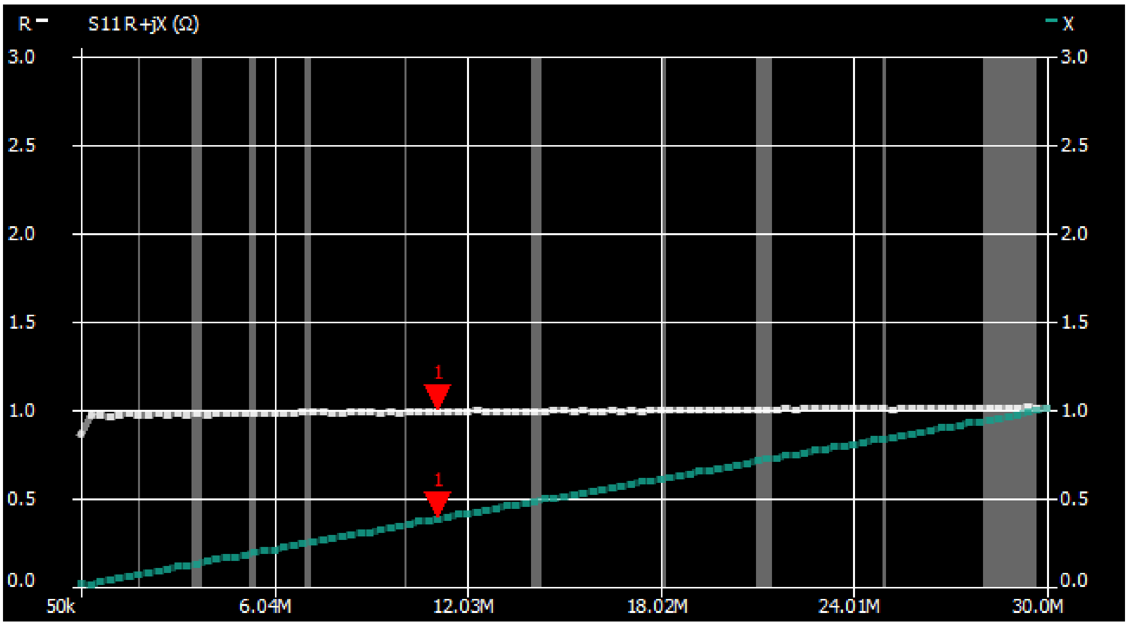
2. The frequency at which μ'_s and μ''_s are equal.
Looking at the chart: here μ'_s is a direct measure for the calculation of the self-inductance L and the reactance XL at varying frequencies. For the low frequencies, this is therefore equal to the initial value μ_i.
The μ''_s is a measure for calculating losses. These are expressed in a resistance value R. Where the two μ's are equal (and thus where R = XL) the ferrimagnetic resonance point is established (reference ON9CVD website). That is about 45 MHz for 4C65. You must therefore be able to use do a high-frequency measurement so as not to considerably increase or decrease the result from this point by MHz.

3. The value of the two μ's at the ferrimagnetic point.
Above, that is at the intersection of the graphs with a value approximately equal to 110.

For the background of these measurement points and μ'_s and μ''_s I refer you to the articles and websites of Owen Duffy and Bob van Donselaar and the article by Mathieu Melenhorst who explain this very clearly (see references), and of course, the 'Soft Ferrites and Accessories Data Handbook (2013)' from Ferroxcube is a great resource. The latter contains numerous graphs and numbers of different core materials.

Measurement of low impedance

At relative low frequencies impedance values can be pretty low. Will the nanoVNA be able to measure that properly? We'll take the short route. We make an S11 R + jX measurement with an ordinary "old-fashioned solderable" 1-ohm resistor. That then provides us the following image (from nanoSAVER)



We can see that the value of 1-ohm is displayed correctly over the entire HF range (between 0.97 and 1.01 ohm) and that there is a linearly increasing reactance. In nanoSAVER you can read that it is about 5nH, reasonable for just average simple resistance. We can therefore cautiously conclude that with a few percent measurement tolerance you can still measure sufficiently well up to 1-ohm.

In Practice

To identify a round toroid, we have to check several things:

1. The color (possibly a given if the color is in a table)

2. The dimensions of the core OD (outside diameter), ID (inside diameter) and H (height)

3. The self-inductance value per 1 winding measured at a low frequency (you then have the AL)

4. Calculate μ_i: Calculate this using one of the tools in the Mini Ring Core Calculator. The operation of which you will see immediately in the measurement of core 1. The μ_i at least gives a first good indication of what toroidal material you are dealing with.

5. Determine the ferrimagnetic resonance point where XL = R (so where $\mu''_s = \mu'_s$). This is especially helping to find the right core with ferrites, because the μ_i's sometimes hardly differ from each other and where tolerances of ± 20% are specified.

6. Determine the value of the µ's in the ferrimagnetic resonance point and the variation at different frequencies.

If you compare all of these measurements to the manufacturer's specs, and it very closely resembles them, you may have found your core material through your identification measurements. Let's try that.

Ferrite Core 1

We start simple (well… simple) with a more or less well-known and widely used toroid core in HF land, a red T200-2. This one is made of iron powder. These types of cores are known to have little core losses in its working range so that with an S11 R + jX measurement the resistance R is much lower in value than the reactance X.

1. The color: red (logical)
2. The dimensions: OD = 51.0 mm; ID = 32.0 mm; H = 14.3 mm; thin red layer of lacquer (0.1 mm thick?)

So far so good, these are the colour and dimensions of a T200-2 according to the data in the Ring Core Calculator.

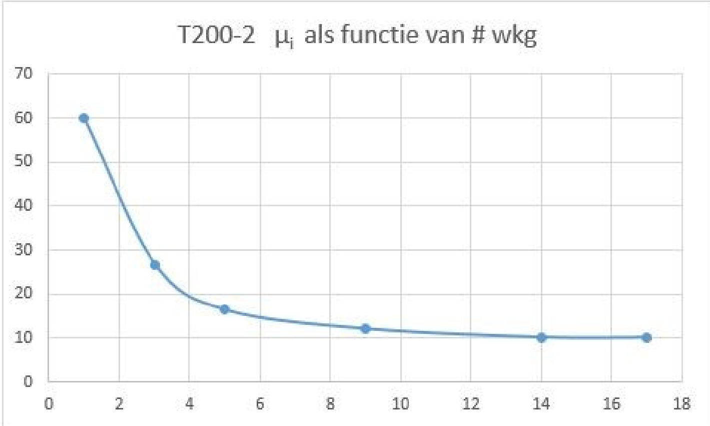
3. Now it is time to measure the number of nH for 1 winding (= AL value). That turns out to be a challenge because the impedance value for 1 winding is quite low and there is more to it as it turns out.

First measure via S11 through the core with a different number of windings to connect. The AL and μ_i turn out not to be as 1-2-3 simple as the expected values. The reason is that the low μ_i of the core causes the magnetic field to leak from the core. That is why we measure with different numbers of windings and we try to encircle the entire core. This is not possible with 1 winding, but with 4 or more it is already easier.

The outcomes using the nanoVNA are surprisingly good. See the following table and graphic. We then end up in the neighborhood of μ_i = 10, which in the specs stands for type-2 material.

T200 - 2

wkg	L (nH)	AL nH/N^2	µ
1	77	77	59,9
3	310	34,4	26,8
5	526	21	16,4
9	1251	15,5	12,1
14	2560	13,1	10,2
17	3760	13	10,1

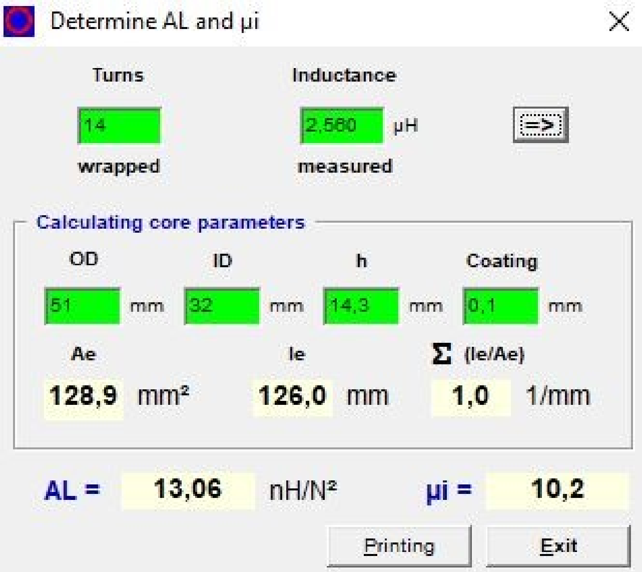


The values from the table above can be found using the "Determine AL and μ_i" tool in the Ring Core Calculator.

Put the data of the core in the green fields. So the dimensions of the core, the number of windings used for the measurement, and the measured inductance from nanoSAVER in a not too high a frequency (say between 50 and 150 kHz).

You can see the result in the image. The tool reports, among other things, AL and μ_i.

All in all, we neatly find the μ_i, albeit through multiple measurements, achievable, and providing sufficient insight.



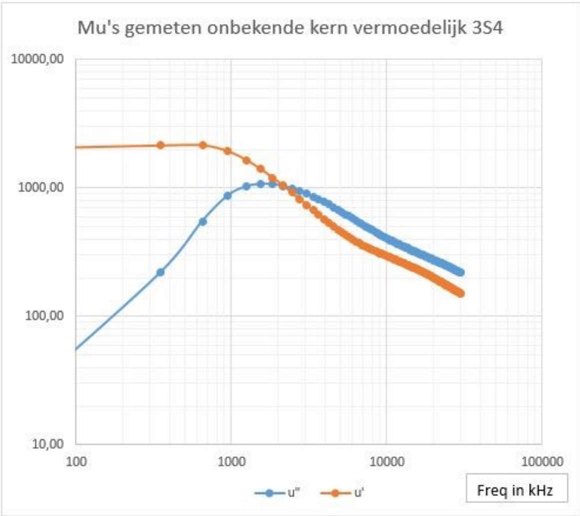
Finding the ferrimagnetic point for this core makes no sense since the loss resistance R will for certain not come close to the reactance X for this type core material. You can see this for yourself by the S11 R + jX measurement. So we will leave it at this. The red color and a measured μ_i of 10 is sufficient evidence.

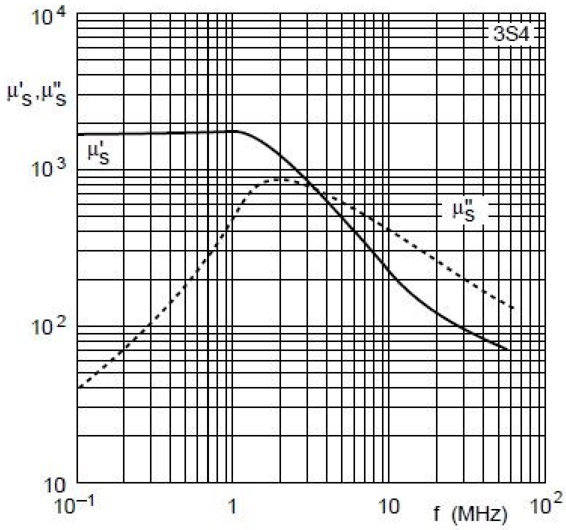
Core 2

This core is black and approximately 35mm in diameter. Type and material to be determined. We will go through the steps.

1. The color: black; we can't do much with that, it's probably ferrite. There is no coating around it.
2. OD = 35.3 mm; ID = 22.8 mm; H = 15.0 mm
3. Measured inductance for one winding (= AL): 2.7 µH at frequencies between 50 kHz and 175 kHz; (with a few more windings you get the same result)
4. Calculation of the μ_i with the ring core calculator tool: approx. 2100
5. Ferrimagnetic resonance point: 2.15 MHz (From S11 measurement R + jX)

6. Value of the μ’s at the intersection point: approx. 1000 and you can further see the result in the graph.





The core material resembles: 3S4, which is officially registered with μ_i = 1700 ± 20%. So, the measured 2100 is on the edge, because there are also other types with these measured values. The reason for choosing 3S4 is the result of the μ’s, which almost conforms to the Ferroxcube specification. On the left you see the Excel chart of the measurement, on the right the picture from Ferroxcube. But if someone can find another suitable picture, that is fine too. It does not always work because of the name, but because of the properties.

The calculation of the graph of the μ’s is done as follows:

- Measure the core with one winding via S11, which is possible here with one winding because I got the same values for AL and μ_i with a different number of windings
- Export the measurement in an S1P file and open it in Excel
- Convert the S11 values to R and X in Excel. You will then receive the data S11 R + jX from nanoSAVER in table form (for formulas see below)
- Convert the R and X values to the two μ’s using AL and μ_i (formulas see below)
- Plot the μ'_s and μ''_s on a logarithmic scale graph

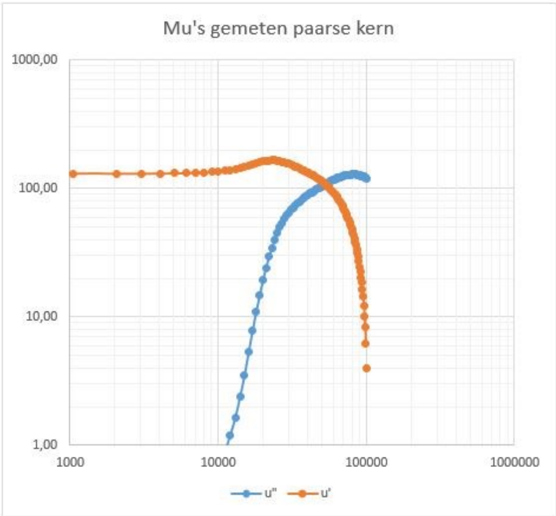
It was not easy to select a core material from the long line. You can find about 10 available specifications from Fair Rite and ditto at Amidon. I did not count them from Ferroxcube. So ultimately, I opted for 3S4 based on how the μ’s conform. It is a matter of comparing many pictures and numbers.

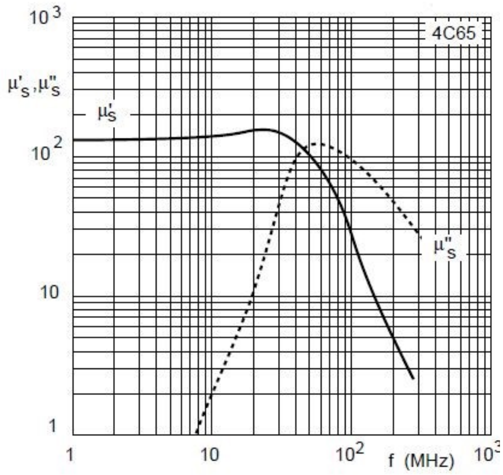
Core 3

Returning to the beginning of this article, I chose as the third core one of the somewhat purple-coloured cores of approx. 35mm, "presumably" of type 4C65.

We will go through the same procedure as with the previous cores. With more and more windings (3 to 5) the measured μ_i quickly moves towards 125. That in itself is a good sign because that number is also in the specs. The problem of leaking flux also plays a role here. At the same time, you cannot use too many windings because to find the intersection of the μ’s. You end up in the VHF area and then the parasitic capacity and the length of the winding wire do play a role.

The results of the measurement were as follows:





The two graphs are remarkably similar. For my measurement, I stopped at 100 MHz. This is a bit high, given the simple measurement setup.

There is a way to measure this better with a single winding. To do this you should hang the core in a metal tube closed at both ends. Orient the middle of one winding facing one flat end and the other the opposite flat wall. The current then flows back to the inner wall of the tube all around the connection and then you have one completely covering winding. I'll gladly accept an offer from someone who can make such a thing for me, so I can give it a try :-) My details are on QRZ.com and at Linked In.

One last remark

About measuring impedance values lower than 1 ohm. This is possible quite accurately with some careful effort and the nanoVNA. It is a bit similar to the way we had very high impedance values that we could measure in Part 2 of this series. How that works for low impedances, and how it works out in practice, will be discussed in part 5 of this series.

73,

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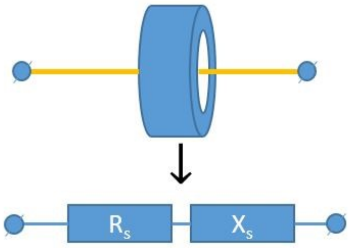
Calculation S11 = Sr + jSi   to Z = Rs + jXs

$$Rs = 50\frac{1-(Si^2+Sr^2)}{(1-Sr)^2+Si^2}$$

$$Xs = \frac{100Si}{(1-Sr)^2+Si^2}$$



Calulating R and X of ringcore impedance to µ-values

$$\mu'' = \frac{Rs * \mu_i}{2\pi f L}$$

$$\mu' = \frac{Xs * \mu_i}{2\pi f L}$$

L is the measured inductance when determining the value of μ_i.
For 1 winding, this equals AL.

References:

1. Owen Duffy: A method for estimating the impedance of a ferrite cored toroidal inductor at RF

https://owenduffy.net/files/EstimateZFerriteToroidInductor.pdf

2. Bob van Donselaar (ON9CVD): Ferrieten in HF-toepassingen Deel 1 (Electron September 2001)

3. Website ON9CVD: http://home.scarlet.be/on9cvd/Ferriet.html

4. Mathieu Melenhorst: Spoelen en kernmateriaal

https://www.hftechnology.nl/downloads/14-01-hftechnology-ferriet-nieuwsbrief.pdf

5. FerroxCube: Soft Ferrites and Accessories Data Handbook 2013

https://www.ferroxcube.com/en-global/download/download/11

6. Amidon: Specifications – Tech Data

http://www.amidoncorp.com/specs/

7. J.J. Carr: Toroïde spoelen zelf berekenen en maken (Elektuur 6-94)

8. Software: Mini Ring Core Calculator V1.3 by DL5SWB / DG0KW

http://www.dl0hst.de/mini-ringkern-rechner.htm